Using a nanosatellite to collect aircraft based observations for meteorology

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Abstract

Opportunistic observations from aircraft have been shown to be an affordable source of new measurements of the upper air atmosphere [2, 6–8]. The potentially most beneficial source of these observations (Mode-Selective Enhanced Surveillance [Mode-S EHS]) requires air traffic management (ATM) secondary surveillance radar to interrogate aircraft for some parameters. This interrogation depends not only on the type of airspace and local ATM infrastructure but also on the chosen regime by the ATM responsible for the airspace. It is therefore very difficult to have a clear understanding of where the observations are available. This paper reports on the reprogramming of a European Space Agency technology demonstrator cubesat (GomX-3) for the collection of ATM data to derive Mode-S EHS meteorological observations. The satellite wad developed by GomSpace and reprogrammed whilst in orbit. The reprogramming and subsequent data collection period resulted in the derivation of 19353 wind observations and from every populated continent. Using a Icosahedral Snyder Equal Area Aperture 3 Hexagonal Grid to bin the data an estimate of the total number of observations that may be available in one day can be estimated by comparison to the same grid applied over the UK using the Met Office ground based network of receivers. this showed that there are potentially over 125 million meteorological observations per day available throughout the atmosphere that are not currently being utilised.

Aircraft based observations are often shown to be an important source of information for numerical weather prediction (NWP). As NWP models increase in resolution novel methods of obtaining observations from aircraft must be investigated to find affordable methods to keep up. The observation type that

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Figure 1: GOMX-3 in fully deployed configuration with helical ADS-B antenna.

is currently showing great promise is Mode-Selective Enhanced Survalliance (Mode-S EHS) [1, 2, 4, 7]. Mode-S EHS allow for good quality wind observations and lower quality temperature observations to be derived from a very large number of civil aircraft when they are flying in some airspaces. The data being limited to certain airspace is because aircraft must be interrogated by air traffic control secondary surveillance radar (SSR) for the specific pieces of information required to derive the meteorological observations. Due to the nature of different countries controls and rules there is limited information available on which national airspace or airports are currently interrogating for the required information. Whilst technically possible it would be costly and time consuming to transport a Mode-S/ADS-B receiver around the world to investigate the likely data availability.

This paper reports on a joint effort from the European Space Agency (ESA), the Met Office and GomeSpace to understand the potential availability of data. GomX-3 (figure 1), a 3-U CubeSat, a small, lightweight, low cost satellite of 3 kg mass and dimensions 10×10×30 cm, was a technology demonstrator built by GomeSpace for the European Space Agency (ESA) [3]. Its primary mission was to demonstrate a 3-axis attitude control subsystem and advanced miniaturised radio technologies, including an improved ADS-B receiver, L-band receiver based on software-defined radio techniques, and a high rate X-band transmitter [3].. It was deployed from the International Space Station on 5 October 2015 and conducted a successful 6-month mission, and re-entered the Earth atmosphere on 18 October 2016.

In April 2016 the Mode-S EHS team at the Met Office in the UK became aware of the European Space Agency technology demonstration project to collect Automatic Dependent Surveillance - broadcast (ADS-B) data to map the locations of aircraft. This data is part of the same standard as Mode-S EHS. ESA, the Met Office and GomSpace agreed an extended mission to reprogram the satellite whilst in orbit to collect the extended range of parameters to allow the wind and temperature observations to be derived. The wind is derived from the difference in the ground movement vector and the air movement vector [7], whilst the temperatures are derived by back calculating from the reported true airspeed and Mach number

After reprogramming the nanosatellite it completed 14 days of orbits collecting data between 51.5° and -51.5° lattitude. The data was transmitted back to

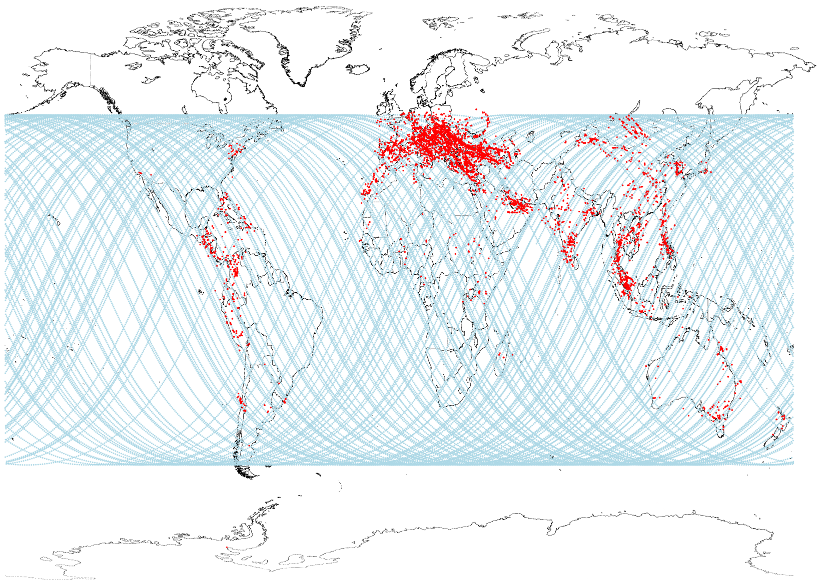

Figure 2: Map showing the derived Mode-S EHS observations collected by GomX-3. The blue lines show the GomX-3 orbital track over the two week period of the trial. The red dots are locations where Mode-S wind and temperature observations were derived and highlight the regions of the world where these data would be available currently. The volume of data obtained was strongly limited by the temporal coverage available from a single satellite.

the ground station operated by GomSpace in Denmark before being delivered to the Met Office Mode-S/ADS-B processing system that generated the wind and temperature observations. The data collection orbits are shown in figure 2 as the light blue data, these were calculated from the timestamped 816769 raw messages. The red dots on figure 2 shows the positions of each derived wind and temperature observation. 19353 observations of wind and temperature were derived.

Considering Singapore; where before this experiment it was unclear as to whether Mode-S EHS observations would be available; there were 5 satellite passes during the collection period. Each pass is represented as a panel in figure 3 with the derived winds being shown as arrows. The direction of arrow indicates the wind direction, the size the wind speed and the colour the altitude of the aircraft. Even without heading corrections being applied to the data the winds are consistent throughout the whole depth of the atmosphere with observations from near the ground up to cruise altitudes being collected.

To assess the number of observations that are likely to be available globally a comparison to data collected using the Met Office network will be used. The GomX-3 derived data was binned into an Icosahedral Snyder Equal Area

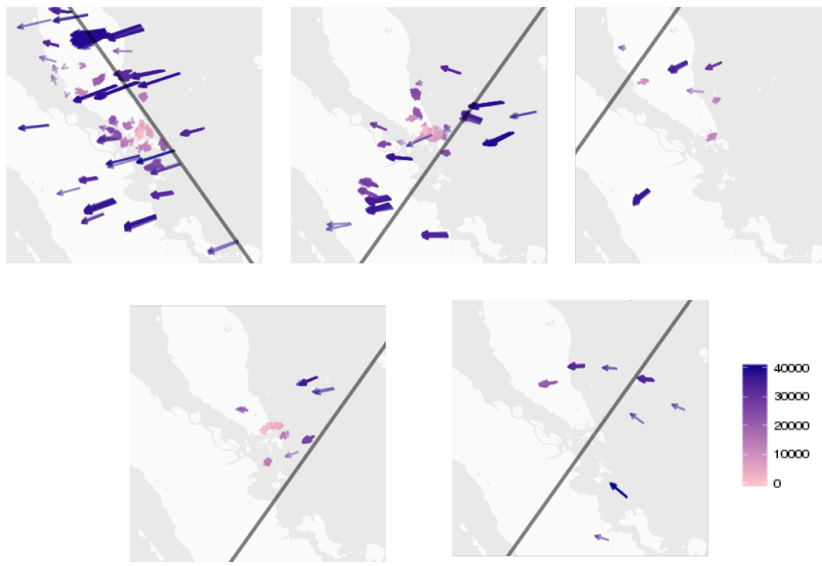

Figure 3: Maps showing the derived wind observations collected by GomX-3 during the extended mission. The size of the arrow indicates the wind speed, the direction the wind direction and the colour the altitude of the aircraft. The dark diagonal lines indicate the satellite track.

Aperture 3 Hexagonal Grid with a centre point spacing of 261 km [5]. 261 km was chosen as being close to the range of a SSR; any aircraft within this box is likely to be interrogated. This resulted in 559 grid points with at least two observations derived from GomX-3; it is assumed that the GomX-3 data is representative of where there are observations but not how many. The same gridding process has been applied to the Mode-S EHS data collected using the Met Office network yielded a range in the number of observations per day. The South West of England was chosen as a typical airspace, containing one commercial airport but with others near by. The grid box covering this area contained ≈225000 observations on the 20th November 2016; The mean number of observations per grid box for the Met Office data was 180000, below the number found in the South West, this is considered acceptable as due to the shape of the UK it contains far more offshore grid boxes than would be typical. Multiplying this number of observations by the number of global grid boxes yields 125775000 observations available per day. This obviously does not include the higher latitudes including the UK; In the UK we know there is ≈ 8 million observations available per day.

The high quality wind data and low quality temperature data provided by Mode-S EHS has been shown to be widely available throughout the world. It has previously been shown that is is feasible to collect this data via national air traffic understructure [1] or through local receivers [7]. It has been shown in this paper that it is also feasible to not only collect this data from space but to do so using a nanosatellite. Future work needs to be done to understand what an efficient future observing system to collect and process this data should look like, including a constellation of nano-satellites providing high temporal coverage. In this respect, the data collected by GomX-3 allows future nano-satellite constellation system architectures to be studied and optimised, in terms of orbit, number of satellites, number of orbit planes, data latency to users etc.

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